Submitted to the:
2003 Particle Accelerator Conference
Portland, Oregon, May 12-16, 2003

BNL – 69593 - CP

VIBRATION STUDIES ON A SUPERCONDUCTING RHIC INTERACTION REGION QUADRUPOLE TRIPLET *

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Abstract

Mechanical vibrations of the superconducting interaction region triplets have been identified as source of horizontal beam jitter around 10 Hz in the Relativistic Heavy Ion Collider (RHIC). Therefore, cold masses inside one triplet cryostat have been equipped with accelerometers to further investigate the phenomenon. Additionally, helium pressure transducers have been installed to determine helium pressure oscillations as a possible primary vibration source. Recent results will be reported.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings ("Blue" and "Yellow") that intersect at six equidistantly-distributed locations around the 3.8 km machine circumference, as shown in Figure 1. During machine operation, horizontal orbit jitter at frequencies around 10 Hz can be detected in both rings [1]. The amplitude of this beam oscillation corresponds to 5 ... 10 percent of the rms beam size for a 6σ normalized emittance of $\epsilon = 10\,\pi\,\mathrm{mm\,mrad}$ at any BPM around the ring, pointing at multiple noise sources. A spectral analysis of this orbit jitter also revealed that spectra in both beams are practically identical, see Figure 2, indicating common vibration sources in both rings.

Since the two RHIC rings share only very few common magnetic elements IRs while the D0 dipoles and the arcs are completely independent (Figure 3), it was soon found that the beam jitter was caused by mechanical vibration of the interaction region triplets which are separate for both beams but share a common cryostat. Figure 4 shows simultaneously measured spectra of horizontal orbit jitter in the "Yellow" ring and of the mechanical vibration of the 4 o'clock triplet. Taking into account the RHIC optics it was shown that the observed jitter amplitudes cannot be explained by the amplitudes measured on the triplet cryostats, but are rather caused by independent vibration of the various cold masses within the cryostat [2].

Since this beam jitter may potentially lead to emittance growth and therefore luminosity degradation due to modulated beam-beam offsets at the interaction points, it is very desirable to find and eliminate its source. We therefore calculated and measured mechanical vibration frequencies of a triplet, and investigated helium pressure oscillations in the cryogenic system as a possible source.

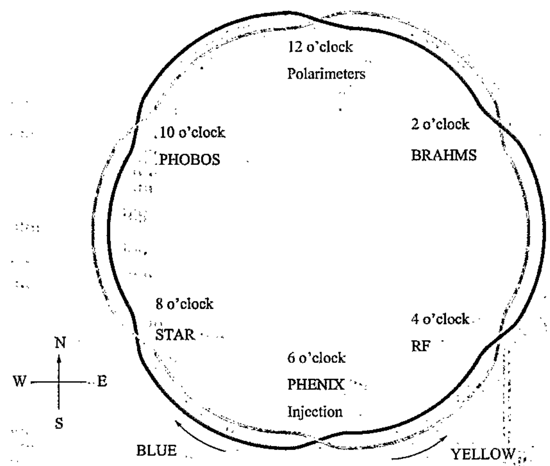

Figure 1: Schematic overview of RHIC with its six interaction regions.

MECHANICAL RESONANCES

Each RHIC triplet cryostat contains the cold masses of three quadrupoles (Q1, Q2, and Q3) and one dipole (D0) per ring, eight cold masses in total. Each cold mass is suspended on two posts, which for mechanical considerations are regarded as springs, see Figure 5. The connection between cold masses is designed to allow independent transverse motion, while it is stiff in the longitudinal direction [3]. Coupled motion of the cold masses can therefore be neglected.

The configuration with two posts allows for two oscillation modes per cold mass, a dipole mode with resonance frequency $f_d = \sqrt{2D/m}$ and a quadrupole mode with resonance frequency $f_q = \sqrt{2Ds^2/\Theta}$. Here, D denotes the spring constant of the posts, m the mass of the cold mass, s the distance from the center of the cold mas to the location of the post, and Θ the moment of inertia of the cold mass. The latter can be calculated as

$$\Theta = \frac{mR^2}{4} + \frac{mL^2}{12}, \qquad (1)$$

where the cold mass is modelled as a solid cylinder with length L and radius R. The parameters of the various quadrupole cold masses as well as the resulting resonance frequencies f_d and f_q of the two modes for a spring constant of the posts of $D = 1.0 \cdot 10^7\,\mathrm{N/m}$ are listed in Table 1. As this shows, mechanical resonance frequencies are

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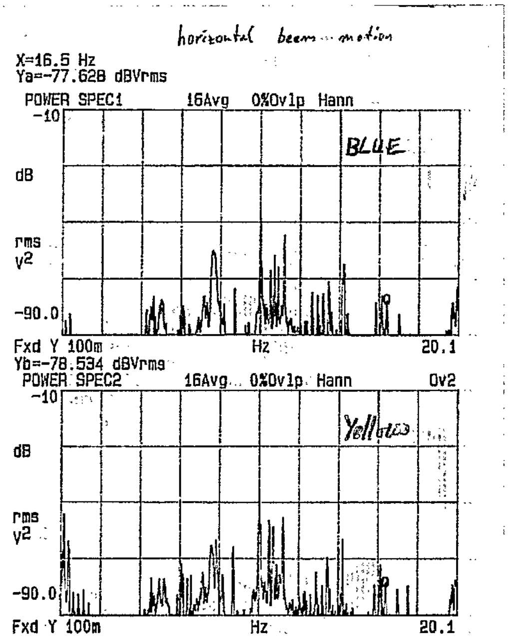

Figure 2: Simultaneously measured horizontal orbit vibration spectra in the BLUE (top) and YELLOW (bottom) RHIC rings.

	Q1	Q2	Q3
m/kg	1130	2580	2260
R/m	0.35	0.35	0.35
L/m	2.24	4.90	4.37
l/m	1.44	3.39	2.10
k/m^{-2}	$-5.76 \cdot 10^{-2}$	$5.61 \cdot 10^{-2}$	$-5.57 \cdot 10^{-2}$
s/m	0.49	1.44	1.19
Θ/kgm^2	481	5182	3614
β/m	404	551	248
f_d/Hz	21.2	14.0	15.0
f_q/Hz	15.8	14.3	14.1

Table 1: Mechanical parameters of the quadrupole cold masses in the triplet, together with the corresponding β-functions, magnetic lengths l, and magnet strengths k for $\beta^* = 2$ m at the IP.

close to those observed on the beam and on the outside of the triplet cryostats. It was therefore attempted to directly measure the mechanical resonance frequencies of the cold masses by attaching an accelerometer to the inside of the beam pipe and measuring the frequency response to a mechanical excitation. This measurement revealed dominant frequency lines at 9.75, 14.0, 16.0, and 19.5 Hz. Except for the lowest frequency at 9.75 Hz, these frequencies are consistent with the mechanical resonances calculated earlier.

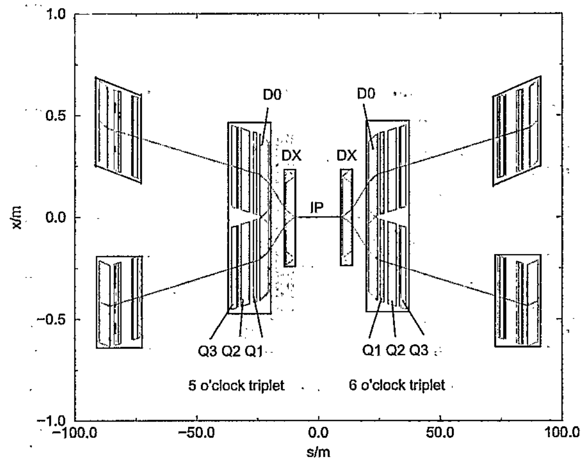

Figure 3: Schematic view of a RHIC interaction region lattice. Both beams collide head-on at the interaction point (IP) and are separated by the DX dipoles. Both orbits are bent back to an almost parallel direction by the D0 dipoles. Strong focusing is provided by superconducting triplets consisting of the quadrupoles Q1, Q2, and Q3.

HELIUM PRESSURE OSCILLATIONS

To investigate the origin of the observed triplet vibrations, helium pressure oscillations in the RHIC cryogenic system were measured. Pressure transducers were installed in the five helium transfer lines (supply (S), return (R), utility (U), heat shield (H), and magnet (M) line, see Figure 6) at the "6 o'clock" valve box and at the six power lead ports of the "6 o'clock" quadrupole triplet crystat.

The magnet line (M) showed a helium pressure oscillation at 10.7 Hz, Figure 7, while no significant oscillations could be detected at the other lines. This frequency was also measured at the power lead ports at the triplet cryostat. This pressure oscillation is caused by the helium recirculator and vanishes when the circulator is turned off. However, though the frequency of this oscillation is very close to the mechanical vibration detected on the triplet cryostat as well as the orbit jitter frequency of the RHIC beam, it could not yet be positively confirmed as the root cause of the magnet vibration and the resulting orbit oscillations.

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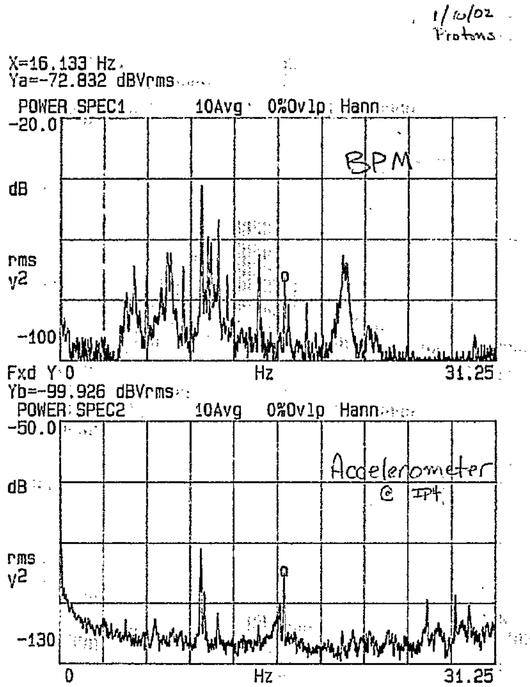

Figure 4: Simultaneously measured beam orbit vibration spectra in the YELLOW RHIC ring (top) and the 4 o'clock triplet acceleration (bottom).

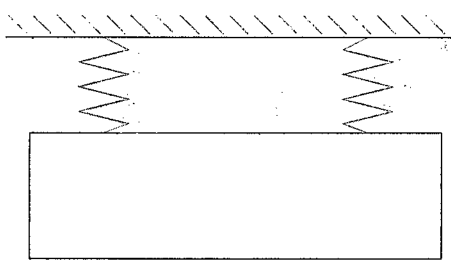

Figure 5: Mechanical model of a quadrupole cold mass suspended on two posts, indicated as springs here.

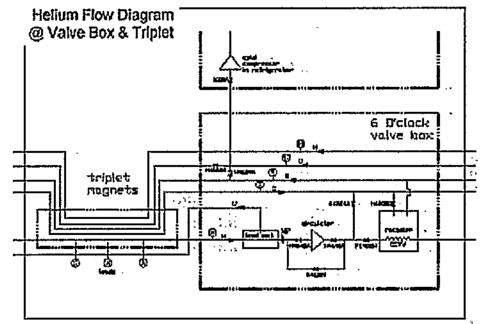

Figure 6: Schematic drawing of the RHIC cryo system. Helium pressure transducers are installed in the five transfer lines, namely the supply line (S), the return line (R), the utility line (U), the heat shield (H), and the magnet line (M). Only three of the six power leads at the quadrupole triplet cryostat are shown, labeled A, B, and C.

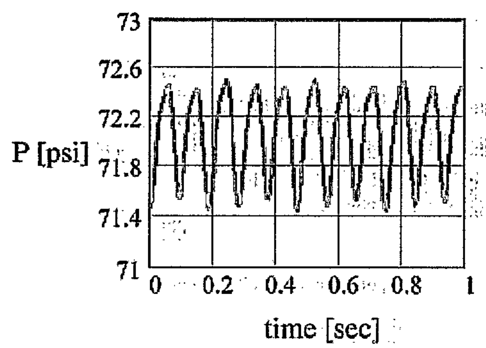

Figure 7: Measured helium pressure P in the magnet line ("M") vs. time. A spectral analysis of this signal reveals a dominating frequency of 10.7 Hz.